PORTLAND CEMENT CONCRETE
OF
UNUSUAL CHARACTER

FOR
WATERPROOFING, LIGHT WEIGHT, INSULATION,
QUICKHARDENING, ANTIFREEZE, PLASTICISING,
SOUNDPROOF AND OTHER UNUSUAL PURPOSES

BULLETIN NO. 23

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PORTLAND CEMENT CONCRETE OF UNUSUAL CHARACTER AND FOR SPECIAL PURPOSES

The purposes for which special or unusual portland cement concrete is made include the following general classes:

(1) Waterproofing.
(2) Prevention of freezing during hardening.
(3) Quick hardening.
(4) Improved workability.
(5) Light weight.
(6) Insulation against heat (fireproofing) and cold (refrigeration).
(7) Soundproofing (sound insulation and improved acoustics).
(8) Prevention of parasitic growths.
(9) Acidproofing of concrete.

1. WATERPROOFING OF CONCRETE

The principal objects in waterproofing are:

Making concrete "water-tight" for prevention of leakage of water.

The prevention of corrosion of steel imbedded in concrete.

The prevention of absorption of moisture causing dampness of walls.

The prevention of expansion and contraction of concrete with resultant disintegration.

The prevention of disintegration by freezing.

Surface waterproofing is accomplished by the application of surface coats such as bitumen, or the application of surface films such as paints.

Integral waterproofing is accomplished by the addition of the agent to the concrete mix and while most desirable, has not been universally successful. The methods of integral waterproofing include the following:

(1) The filling of the voids with fine inert inorganic filler such as tripoli, fine sand, silica, pumice, clay and the like. Fine round-grain silica tends to give the greatest density and waterproof qualities of any substances in this class.

(2) The use of water-absorbent, inorganic material such as bentonite or gelatinizing clay. These substances act by reason of the property of swelling with water. Bentonite or gelatinizing clay absorbs as much as ten to twenty times its weight of water, forming a gel. One method of incorporating the bentonite is to first mix it with a relatively small amount of oil distillate such as kerosene. To prepare a mixture for this purpose, the bentonite may be thoroughly dried and ground to pass about an 80-mesh screen. It is then treated with 5-10% of kerosene and added to the concrete in the proportions of from 2-5% of the weight of the cement used, or so that it represents about 10% of the weight of the water used in mixing the concrete. This amount, of course, varies with the quality of the bentonite. The purposes of the kerosene are to prevent the ben-

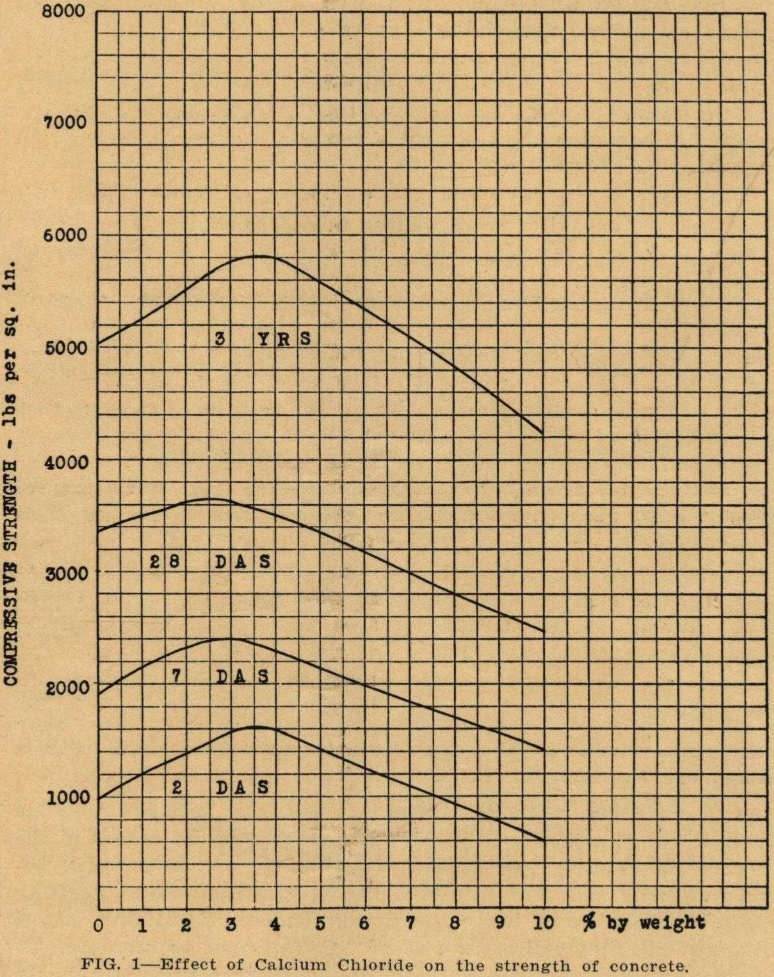

FIG. 1—Effect of Calcium Chloride on the strength of concrete.

tonite from balling up or forming a gummy mass in the concrete mixer, as it is necessary for it to divide itself into its final particles as much as possible while being mixed and to delay the water absorption of the bentonite so that the swelling will not take place fully until the concrete has set and the oil has been dispersed through the entire mass of the concrete or has been allowed to evaporate. When the concrete has fully dried, evaporation takes place, and the bentonite is now fully susceptible to the action of water, so that when water comes in contact with the outside of the mass of concrete the bentonite swells in the surface and thus prevents further ingress of water. Theoretically this type of material is the ideal integral waterproofing substance.

Hydrated lime has been used for the same purpose, but it does not form a gel with water. After being placed in the concrete it forms calcium carbonate, which tends to make a more dense concrete.

(3) Waterproofing by the use of water repellent substances such as insoluble soaps, hydrocarbon oils and pitches in very small quantities. This type of integral waterproofing depends upon the tendency of fatty acids, metal soaps and oils to repel water, thus overcoming the capillarity of concrete. As little as .05% of fatty acid in the form of soap, based on the weight of concrete, provided it is uniformly distributed and the concrete is dense and free from cracks, is often quite effective for integral waterproofing. Such treatment will not in itself entirely prevent the penetration of water, even under very slight pressure, but it will materially reduce the amount of water that will be absorbed or will greatly retard the rate with which water may penetrate. Coal tar pitch has been used in the same manner and has been effective to some degree. Likewise, hydrocarbon oils such as petroleum residues and fuel oils have been used either alone or after mixing with an inorganic carrying agent such as diatomite.

(4) Waterproofing by the use of considerable quantities of bituminous material. By this method large quantities of liquid, semisolid or solid bitumen are used, and the purpose is different from that of obtaining a water-repellent action. Sufficient bitumen is used to actually dam off the ingress of water. While the voids may not be completely filled, sufficient material is used so that there is no continuous passage for the water. As a typical instance, for the waterproof action where the repellent action only is desired, less than 3% of the hydrocarbon, asphalt or pitch is used, based on the portland cement, whereas, where occlusion of the voids is desired, an amount greater than 25% of the cement is ordinarily used. If this waterproofing occluding material is of a liquid nature, it has been found that it is not sufficiently effective, as the pressure of the water or the capillarity of the concrete causes dissemination of the waterproofing material. If, however, the bitumen is of sufficient viscosity that the capillarity is overcome, such as is the case with semi-solid or solid asphalt or bitumen, then the waterproofing is perfect. As a

typical instance of the application of this method of waterproofing, a mixture may be made as follows:

Portland cement	120 lbs.
Sand	240 lbs.
Rock	480 lbs.
Finely divided bitumen such as 35 penetration asphalt finely crushed or emulsified	50 lbs.
Water sufficient to make plastic, ordinarily about	120 lbs.

This mixture may be made more plastic by the use of 10 pounds of bentonite. Such concrete may be used for the making of blocks or other formed objects, in which case it is ordinarily steamed to accelerate the hardening of the blocks. At the same time, the bitumen is thoroughly fused into the voids, thus making a perfectly waterproof block. Or, on the other hand, with the right character of bitumen, there may be just sufficient fusion to seal the voids without complete dissemination or loss of waterproofing qualities. Where the concrete is subsequently subject to higher temperatures, asphalts of lower penetration may be used. Ordinarily it is desirable to use asphalt having a melting point of over 100° F., the principal guide being to use the lowest melting point that will allow thorough fusion into the concrete. In all cases where waterproof concrete is desired, it is important, of course, to use as much cement and as much plasticising agent as is feasible to get a perfectly uniform and strong concrete in which there will be no segregation. One of the worst causes of porous concrete is excessive segregation of the aggregates, causing honeycombing.

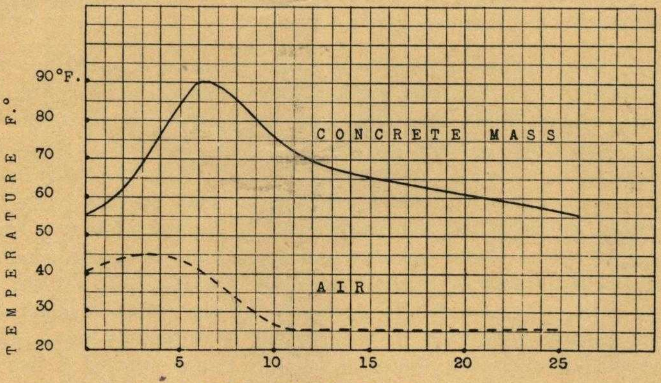

FIG. 2—Graphic illustration of the value of heating concrete materials in cold weather.

2. PREVENTION OF FREEZING OF CONCRETE

Another special type of concrete admixture is for the prevention of freezing in cold weather. Various substances have been used for this purpose, the most common of which are calcium chloride, magnesium chloride, and ordinary salt or sodium chloride. Many substances under trade names have been used and sold, but practically all of the successful ones have calcium chloride as the active ingredient, mixed with other more or less inert substances. Any substance which will not retard the setting or interfere with the hardening of the cement and will lower the freezing point of water may be considered satisfactory for preventing the freezing of concrete. In many localities the average winter temperature is very close to the freezing point, so that normally the small lowering of the freezing point effected by these substances is adequate. The following table gives the effect of calcium chloride and common salt on the lowering of the freezing point:

Solution, Per Cent by Weight	Freezing Point, Degrees Fahr.	
	Common Salt	Calcium Chloride
5	25.2	27.7
10	18.7	21.4
15	6.1	—1.5

It will be seen from the above that 5% of common salt lowers the freezing point about 6° F. However, this amount of common salt mixed in the water for concrete reduces the compressive strength of the concrete at 28 days about 30%, whereas 6% of calcium chloride gives the normal strength. In concreting in cold weather, therefore, it will be seen that all material should be placed in the work at a temperature very much above freezing, and the only dependence to be placed upon the protection from calcium chloride would be in maintaining the freezing temperature of the concrete below the average air temperature. A typical January temperature rarely goes below 30° F. Since at times zero weather is encountered, a mass placed during zero weather must be heated, but if once placed at a temperature above the freezing point, then 6% of calcium chloride will amply protect for any temperature which the mass of concrete will attain. Magnesium chloride is unsatisfactory for prevention of freezing of concrete, due to the reduction of the strength, although the lowering of the freezing point is greater than calcium chloride. Figure 1 shows the effect of the admixture of calcium chloride on strength. In making mixtures of calcium chloride it is to be borne in mind that commercial calcium chloride usually contains about 75% of the pure substance.

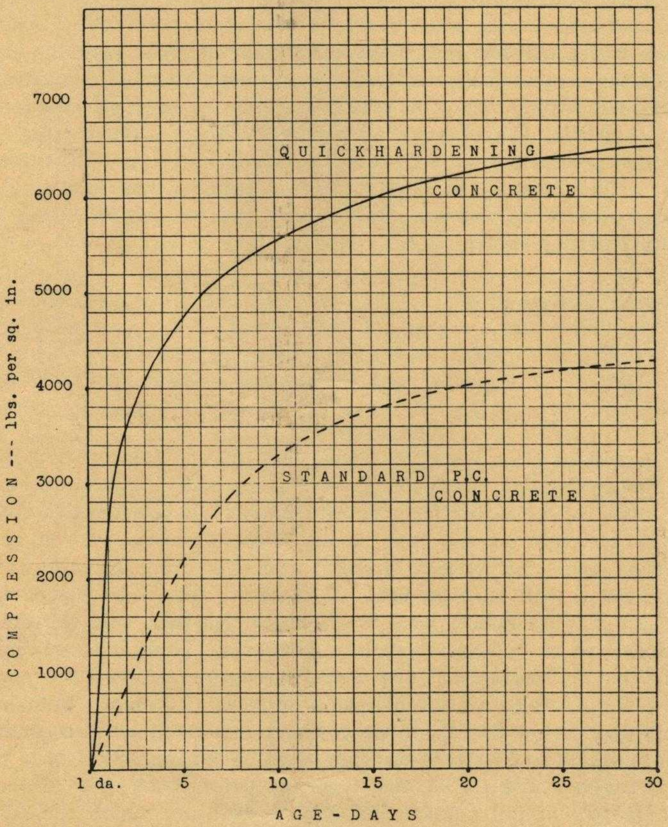

FIG. 3—Strength of concrete made from quick-hardening (but not quick-setting) portland cement compared with standard portland cement concrete.

3. QUICK HARDENING CONCRETE

Any discussion of the use of calcium chloride opens up consideration of special concretes in which quick hardening is desired. Calcium chloride is very extensively used for this purpose. The principal applications of such concrete consist in the cementing of oil wells, quick repair of pavements, surface curing of pavements, and miscellaneous repairs where it is necessary to get the concrete into service very quickly.

For the purpose of a better curing of a concrete pavement, calcium chloride solution may be sprinkled over the surface, thus holding the water by hygroscopic effect and preventing evaporation of water from below.

Much attention is now being paid by manufacturers of hydraulic cement to quick hardening cements ready for use. These cements are of two general types, one being those made from bauxite or having a very high content of alumina, the second being special portland cements in which there is a slight variation in the normal mix with unusually fine grinding and to which some agent has been added to produce, possibly by catalytic action, quicker hardening without materially affecting the setting time. High alumina cement varies widely in its composition. The cement of this type most widely used in this country is known as "Lumnite," which has given a tensile strength with a 1-3 mix of about 460 pounds per square inch after 24 hours, or a compressive strength with a 1-3 mix of approximately 4700 pounds per square inch. Other brands are sold in Europe under the trade names of "Lightning," "Ciment Fondu," and "Alca." A great variety of results has been obtained in practice using this type of cement, with the result that the trade in general is not entirely satisfied.

Largely on account of the uncertainty of behavior of some of the high alumina cements as found on the market, straight portland cements having very high early strength are now being extensively sold. Among these brands are "Quickard," "Ferrocrete," "Supercement" and "Hydroplastic." Some of these portland cements are capable of giving a 24-hour concrete strength equal to the strength of ordinary concrete at 28 days.

A comparison of concrete made from ordinary portland cement and special quick-hardening portland cement is shown in Figure 3.

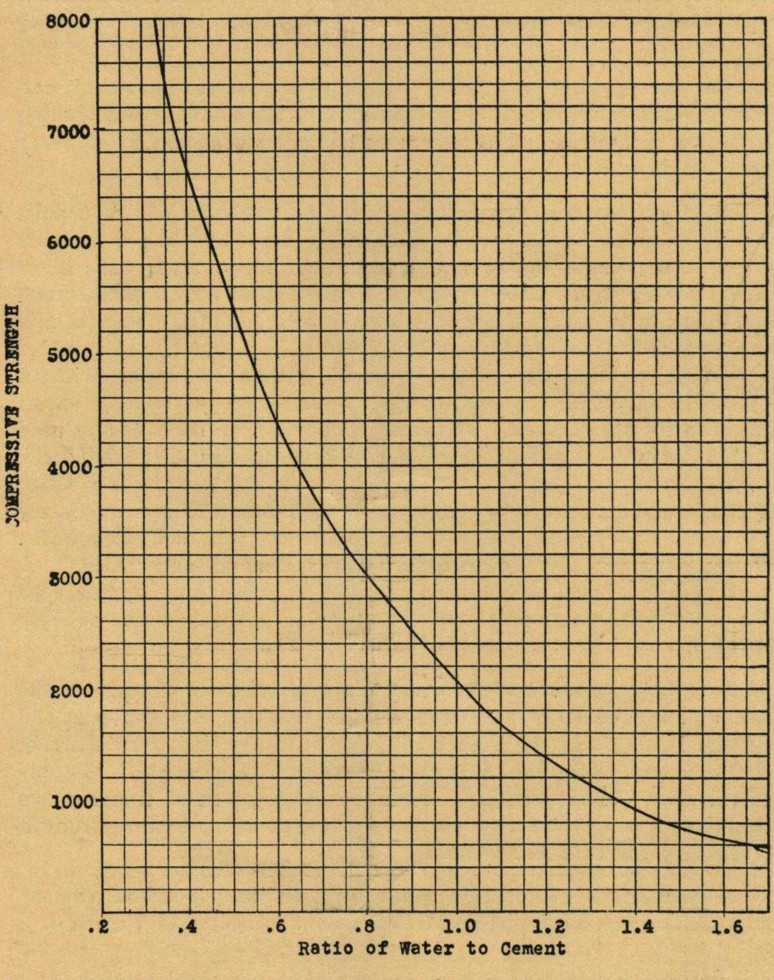

FIG. 4—Effect of mixing water on the strength of concrete and mortar.

A comparison of the composition and properties of various hydraulic cements is as follows:

CHEMICAL COMPOSITION

	Natural Cement	Plain Portland Cement	Quick Hardening Portland Cement	High Alumina Cement
Lime (CaO)	53.7%	61.91%	65.27%	39.91%
Alumina (Al_2O_3)	12.1%	7.92%	7.10%	39.53%
Iron Oxide (Fe_2O_3)	3.5%	2.40%	2.12%	15.41%
Silica (SiO_2)	26.7%	20.65%	21.32%	2.59%
Magnesia (MgO)	3.6%	3.54%	1.40%	0.73%
Sulphur (SO_3)	0.2%	1.35%	1.85%	0.21%
Alkalies, Chlorides, etc.	....	0.5 %	.....	.....

TENSILE STRENGTH—Lbs. Per Square Inch

1-3 Sand Briquets—				
24 hours	0	0	330	464
7 days	120	250	430	537
28 days	180	400	538	561

COMPRESSIVE STRENGTH—Lbs. Per Square Inch

1-3 Sand Cylinders—				
24 hours	0	0	3755	4725
7 days	400	2500	9891	4985
28 days	1800	4500	12212	5004
1-2-4 Concrete—				
24 hours	0	400	2130	2865
3 days	250	1200	3457	3542
28 days	1500	3800	5690	3891

FINENESS

Passing 200 mesh	95%	85%	95%	97.6%

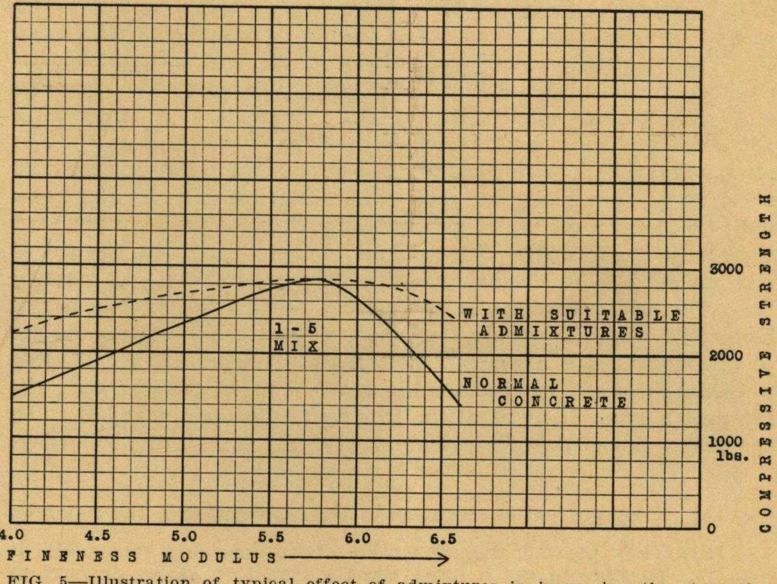

FIG. 5—Illustration of typical effect of admixtures in increasing the strength of concrete.

4. WORKABILITY OF CONCRETE

Possibly the greatest interest in the use of admixtures has been occasioned by substances put in the concrete for the purpose of improving the workability. Such substances include:

(1) Any type of very fine aggregate such as fine silica, quicksand, pumicite, diatomite, tripoli, limestone dust, kaolin, clay, or other inert filler or "lubricating" agent.

(2) Substances having a water-holding, sponge effect of the type of diatomite (celite) and other porous or cellular minerals. Such substances not only have a purely physical effect in filling voids but also retain water more completely in the mixture.

(3) Substances having both a water-holding capacity and having chemical or hydraulic properties, such as hydrated lime and natural cement.

(4) Gelatinizing clays or substances of the nature of bentonite, which form a gel with water. Such substances have the capacity of taking up from 5-20 parts of water by weight, and do not act as filler or fine aggregate.

It is a well established fact that the strength of concrete is dependent largely upon the ratio of water to the cement content. (See Fig. 4. Any substance or admixture added which increases the amount of water required in most cases will decrease the strength of the concrete. This is not the case in those instances where a very lean mix is used and where the admixture aids in filling the voids of the concrete, for then the disadvantages of the higher water-cement ratio are more than offset by the increased compactness of the concrete. The possibility of reaction of the cement with colloidal silicates such as bentonite has been suggested in giving increased strength. The use of admixtures with rich mortars or concretes is not always advantageous, though some type of admixture is nearly always desirable in lean concretes. However, strength is not the only consideration in making concrete. If it is possible to make a concrete more uniform by the use of an admixture, then for practical purposes the concrete is stronger. The weakest concrete made with the use of admixture might be stronger than the weakest concrete made without the admixture, although the strongest concrete made by the use of admixture might be weaker than the strongest made without the use of admixture. It is a well known fact, for example, that in pouring a vertical element in concrete the lower part is stronger than the top part because of segregation. In general, the advantages of using the proper admixtures to improve workability include the following:

(1) They prevent segregation of the aggregates in the concrete.

(2) They prevent the separation of laitance and thus make it possible to get a hard, smooth finish on floors or next to forms.

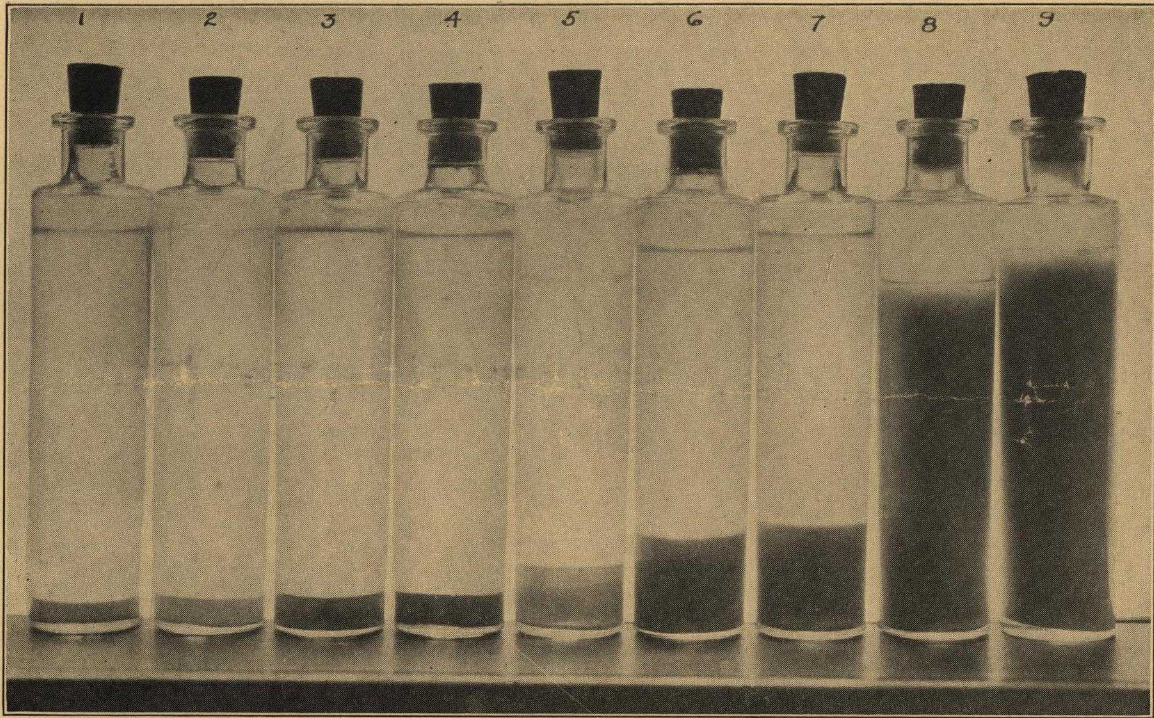

FIG. 6—Illustration of the water-holding capacity and plasticising effect of equal weights of various substances used as admixture for concrete and mortar. (See page 15.)

(3) They make it possible to handle the concrete with greater facility by improving the flowing qualities when placed at long distance from the mixer. This also allows better movement of forms in continuous work, such as grain bin and chimney construction, and easier placing around reinforcement, with consequent reduction of labor and increase in speed of the work.

(4) They make possible the production of a more uniform concrete, both as to appearance and strength.

(5) They increase the minimum strength of concrete and often the average strength, particularly in the case of very lean mixtures. (See Fig. 5.)

(6) They make possible greatly increased speed in concreting work where the greatest strength is not necessary, for instance, in such cases as the fireproofing of structural steel.

(7) The concrete may be made to take the forms much more perfectly and give a surface which requires little labor in finishing.

(8) They prevent leakage of cement from forms and, in many instances, provide for types of construction which are otherwise not possible. An illustration of this was in the case of a structural steel building in which the floor forms consisted of expanded metal. Prior to the use of any admixture it was practically impossible for the expanded metal in the floor construction to retain the concrete. However, after some specially treated bentonite was used, the work progressed rapidly without leakage through the forms and without the necessity of tight lumber forms. (See Fig. 8.)

(9) In some instances the increased yield of concrete or the bulking effect from the use of certain admixtures is quite noticeable. This is due almost entirely, however, to elimination of leakage from the form work. This fact provides not only for greater yields but for greater smoothness of the concrete finish.

As an illustration of the effect of certain admixtures on the strength of concrete, the following table is representative:

ADMIXTURES ADDED TO IMPROVE WORKABILITY

Admixture (a)	Ratio Water/Cement	Crushing Strength Lbs. per sq. in. 7 Days	28 Days
Plain concrete	1.18	1109	2290
3% diatomite (b)	1.23	948	1915
3% talc	1.19	928	1976
3% treated bentonite (c)	1.22	1066	2132
3% hydrated lime	1.21	824	1679

(a) Slump test less than ½ inch in each case; 1-2.5-5 mix.
(b) "Celite" U. S. Patent No. 1,584,579.
(c) "Aquagel" U. S. Patent No. 1,601,295.

As an illustration of the properties of different types of admixtures that are used or sold for improved workability, the photograph of the water absorption is shown in Figure 6. In each of the bottles was weighed five grams of the admixture, and to the bottle was added 100 cc. of water. It was observed that by reason of the addition of water there was no increase in volume of any of the materials except the treated bentonite samples, one being "Aquagel" and the other sold under the trade name of "Colloy." The sample of diatomite occupied the greatest volume dry. The only material having an effect on the viscosity of the mixing water was the bentonite. It will also be noted that portland cement has very little plasticising effect compared with hydrated lime, diatomite or bentonite. Most of the other substances function by being merely physical fillers. The key to these samples is as follows:

(1) Talc.
(2) Pumice.
(3) Portland cement, 24 hours' hydration.
(4) Silica.
(5) Hydrated lime.
(6) Portland cement after 20 days' hydration.
(7) Diatomite (celite).
(8) Treated bentonite or Colloy.
(9) Treated bentonite or Aquagel.

5. LIGHT WEIGHT AND FIREPROOF CONCRETE

The most important departure from the usually recognized types of concrete has been in the manufacture of light weight aggregate and light weight mortars for light weight concrete. The chief problem in production of such a material has been that of attaining sufficiently high compressive strength. The methods pursued have consisted in the use either of a cellular aggregate or a porous mortar. Light weight aggregates are obtained from the following sources:

(1) Cinders from boiler plants especially selected and washed.
(2) Specially manufactured aggregate by heating crushed shale to incipient fusion and intumescence as provided for in the U. S. Olsen Patent No. 1,314,752, and the British Patent No. 132,593 of 1919.
(3) From swelled bricks or burnt clay which has been prepared by pulverizing and admixing with proper flux materials or gasifying substance such as organic material.
(4) Crushed coke, as obtained by the high temperature coking of coal or pitch.
(5) Tufa or pumice, as naturally found in mountain districts.
(6) Furnace slags from metal refining.

The use of porous aggregate has, until recent years, been limited most largely to the use of cinders, and a typical illustration of the properties of cinder concrete is shown in the following table, taken from the Engineering News of 1913:

WEIGHT AND COMPRESSIVE STRENGTH OF CINDER CONCRETE AS USED IN FIREPROOF FLOORS, NEW YORK CITY

(The table covers 120 samples. Each figure given is the average of ten samples. From Engineering News, 1913.)

	A	B	C	D
Mix	1:2:5	1:1:5	1:2:5	1:2:5
Weight, lbs. per cu. ft.	107	100	107	109
One-Month Test:				
Crushing strength, lb. per sq. in.	407	507	818	980
Mod. of Elast., lb. per sq. in.	924,600	857,400	1,230,000	1,492,000
Two-Month Test:				
Crushing strength, lb. per sq. in.	701	662	1,254	1,305
Mod. of Elast., lb. per sq. in.	1,134,000	1,030,000	1,740,000	1,428,250
Six-Month Test:				
Crushing strength, lb. per sq. in.	933	754	1,744	1,478
Mod. of Elast., lb. per sq. in.	971,000	1,050,000	1,348,000	1,276,000

NOTE: B was hand-mixed; A, C and D were machine-mixed. The modulus of elasticity was determined at a point of the elastic curve corresponding to one-fourth the ultimate strength. (Compare with strength of concrete from artificial burnt shale aggregate on following page.)

In about 1918, however, on account of efforts to make concrete ships, much work was done in the burning of shale and clay. One boat, after nearly ten years, is still in successful operation. It has a displacement of 7,500 tons and is now used as a tanker by the Associated Oil Company of San Francisco. It carries 20,000 barrels of oil at one time. Since that time at least four commercial plants have been built for the burning of shale to make light weight aggregate, and one plant which is now in successful operation for the burning of clay for aggregate. By the use of this material concrete may be made which is as strong as concrete made from the usual type of aggregates. This is illustrated by the following tests, representative of several hundred tests of actual field concrete of light weight aggregate made by the Haydite Company in Kansas City, Missouri. The size of the specimens were standard 6-inch cylinders, 28 days old, 1-2-4 mix.

Actual crushing strength	81,770 lbs.	73,050 lbs.
Crushing strength per sq. in.	2,892 lbs.	2,584 lbs.
Weight per cu. ft. of dry concrete	96.2 lbs.	99.6 lbs.

As an illustration of the same material used in manufacture of standard dry-mix (1-10) building blocks, the following is representative:

No.	Size of Block	Area Loaded	Crushing Strength Actual	Crushing Strength Per sq. in.
1	8x8x16″	128 sq. in.	120030 lbs.	939 lbs.
2	"	"	152010	1187
3	"	"	151670	1184
4	"	"	116770	911
5	"	"	142920	1116
6	"	"	118650	927

Weight of blocks = 28-30 lbs. (each replacing 12 brick).

Poured or cast concrete blocks (such as "stone tile") are somewhat stronger on account of the richer mix.

Normal concrete has a weight of about 150 pounds per cubic foot, and it is apparent then that light weight concrete of equal strength weighs from 90 to 105 pounds per cubic foot. The advantages in its use include:

(1) A marked saving in steel, either in structural steel buildings or reinforced concrete buildings, on account of the much lower dead load.

(2) The ability to provide additional stories or space with the same foundation load.

(3) The saving in net space on account of the smaller columns and beams.

(4) The greater amount of superstructure capable of being put on existing foundations or substructure.

(5) Improved fireproof qualities due to elimination of spalling and cracking, and due to a lower required thickness of insulation, thus providing for further reduction of dead load.

(6) Elimination of cracking due to the greater flexibility of the aggregate.

(7) Light weight for paving bridges, floors or for long-span structural elements.

(8) Less labor in placing and lifting.

Where the greatest strength is not absolutely necessary, it is possible to make light weight concrete by allowing the formation of gas in the mortar, using aluminum dust. This method has been used considerably in Sweden, where it has been known as the Billner process. It has been used in the construction of some large buildings in Stockholm and London and for other special purposes. It is apparent that this combination with light weight aggregate will make an even more desirable material from the standpoint of weight. The mortar may be made yet lighter in cases where very little strength is required, by the use of gelatinizing clay in the mortar, or it is possible to make concrete fulfilling many important structural purposes as light as 40 lbs. per cubic foot. For fireproofing purposes it is possible to make concrete as light as 70 lbs. per cubic foot. The use of gelatinizing clay along with the light weight aggregate is almost a necessity to overcome the cinder-like harshness from the tendency of these aggregates to float or otherwise segregate. The colloiding effect of the gelatinizing clay on the water makes it possible to perfectly place this type of material and to easily run it through spouts and into forms.

Illustration of a light weight, fireproof concrete mixture when strength is not the primary consideration:

	Parts by Weight	Per Cent	Wt. per cu. ft.
Cement	2.5 lbs.	6.94	6.55 lbs.
Burnt shale sand	7	19.45	18.37
Burnt shale rock	14	38.90	36.75
Aquagel	1	2.78	2.62
Celite powder	1	2.78	2.62
Kerosene	0.5	1.39	1.31
Water	10.0	27.78	26.24
	36.0		

Weight of specimen: Wet—9 lb. 4½ oz.
Dry—7 lb. 7 oz.

Weight of mix per cu. ft.—94.4 lb.
Weight of dry concrete per cu. ft.—75.0 lb.
Crushing strength 28 days—775 lbs. per sq. in.

On a fire test carried out in the Kansas City Testing Laboratory comparing the common red clay brick, ordinary limestone concrete and light weight concrete made by using burnt shale aggregate, it was found that upon heating each type of material to 1700° F. the common brick completely disintegrated when plunged into water, the limestone concrete completely lost its strength, and the concrete made from burnt shale still carried the load of 1,690 pounds per square inch. It continued to carry the load until the temperature of complete fusion was reached, and at 1900° F., after immersion in water while hot, carried a load of 540 pounds per square inch.

6. CONCRETE FOR INSULATION

The consideration of light weight concrete is intimately bound up with heat insulation, so that an enumeration of the uses of light weight concrete includes its uses for various types of heat insulation. These various uses include the following: The fireproofing of steel on buildings and bridges, boiler settings, still settings, bridge floors both for reasons of fireproofing and light weight, roofs, chimneys, standard building blocks, curtain walls in buildings, floors, building superstructures and portable tanks. Particular interest attaches to the use of light weight concrete for additions to buildings. In some cases, where it has been found impossible to build more than one or two additional stories to large structures on account of the foundations or the other substructure, by the use of light weight aggregate it has been possible to add many times the space.

For insulation purposes, it may be figured that concrete made from light weight aggregate or by the use of cinders has a thermal conductivity of 2.4 B.T.U. per square foot per each inch thickness per 1° F. difference in temperature per hour. The thermal conductivity coefficient for ordinary concrete is about 8.0. The consideration of light weight aggregate leads one almost inevitably to the favoring of the burned shale, due to its inert qualities and the much lower cost of making it. Shale commonly contains the right amount of organic material for uniform intumescence. When properly made, it has as much strength as average stone aggregates and, of course, having once been thoroughly burned, it is not subject to disintegration as a result of fire or as the result of the formation of sulfuric acid. Cinders, while in some respects and in some instances fairly satisfactory, must be carefully selected, and are always subject to danger from the corrosive action of the sulphur on the reinforcement steel, and never yield the strength given by the burnt shale aggregates. Burnt clay is capable of furnishing material nearly as good as shale. It has the disadvantage of greater cost of burning, due primarily to the necessity of pulverizing and in some instances of mixing in the proper amount of water and organic material. (See U. S. Patents Olsen 1,314,752, Hayde 1,255,878.)

7. "SOUND-PROOF" CONCRETE

One of the most desirable features of concrete is that of producing a sound-proof wall. A wall to be sound-proof in the broadest sense must have the property of not allowing sound to pass through, as well as of overcoming the reflection of sound waves, or what is commonly known as reverberation. It has been found that in actual practice a rigid wall which on the surface is highly porous is a very good sound-proofing material. For example, walls made up with cinder or other light weight porous blocks are excellent not only in preventing the passage of sound but in overcoming its reflection. This is apparently due to the fact that the sound waves *pass into the openings between the particles and within the particles* without reflection. Yet sufficient rigidity is necessary to prevent the passage of these waves. This application may be in the form of plaster as well as in the form of the solid light weight walls. Figure 6 shows a theoretical cross-section of a portion of sound-proof plaster. The best sound-proof wall would be composed of:

(1) A structural element of good compressive strength, preferably light weight, and impervious to sound waves.

(2) An element consisting of highly cellular material with a maximum of voids between the particles, such as porous sand mortar, for absorption of sound.

(3) A sound-pervious, non-rigid and preferably smooth surface coat giving the minimum of sound reflection, such as textile coverings or films.

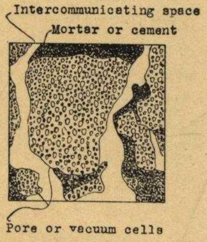

FIG. 7—A theoretical section of sound-proof plaster.

8. PARASITE-PROOF CONCRETE

Concrete is without question the best available material for resisting the disintegrating influences of parasitic growths. It is far superior to metals and timber and is the most economical type of construction. However, in some instances much trouble is occasioned by parasitic growths on concrete causing either disintegration of the concrete or limitation of the usefulness of the particular construction. Much of the damage from parasitic growth is associated with the lack of waterproof qualities of the concrete. Such being the case, a type of concrete has been devised which not only gives the concrete waterproof qualities but also immunizes it against surface or integral growths of fungus, other vegetable parasites or animal parasites, such as teredo. The principle of this preservation resides in the fact that insecticides insoluble in water are available which are soluble in paraffin, asphalt or other bituminous materials. Such insecticides include arsenical compounds of the type of triphenyl arsin and arseno anilido dimethyl ether. Likewise, fungicides or poisons to plant growth insoluble in water are available which are soluble in oil. A typical illustration of this type of compound is copper oleate, which very markedly restricts the growth of fungus and algae. To make such concrete the asphalt or paraffin solution of the fungicide, algacide or parasiticide, or any combination of them, is incorporated in the concrete before setting, as described under integral waterproofing. Such concrete may be made into piling for sea water, irrigation ditches, irrigation pipes, water conduits, sewer pipe and the like, and effectively provides against the action of parasitic growths.

9. ACID AND CORROSION-PROOF CONCRETE

Acid and corrosion-proof concrete is now made to some extent by impregnating ordinary concrete at high temperatures either with high melting point asphalt or with elementary sulphur. The first method has been most extensively applied to the treatment of piling for resistance to seawater and, to some extent, for the treatment of sewer pipe. The latter treatment has been applied most largely in the treatment of large electrolytic cells. Sulphur impregnated or sulphur indurated concrete, as it is sometimes called, has been used successfully for approximately three years in the electrolytic field, where the concrete has been under the action of high corrosive solutions such as hot ferrous and ferric chloride solutions. In this application, the electrolytic cells were immersed in a bath of molten sulphur, remaining in this bath for a period of eight hours and at a temperature of from 130° to 180° C. The sulphur apparently penetrated all surfaces uniformly for at least one inch in depth. There apparently has been no deterioration, in spite of the fact that the cells were reinforced with metal. In the treatment, all moisture is completely driven out of the concrete and the sulphur not only protects against the action of acids but prevents the ingress of any moisture and, in this manner, prevents corrosion of the steel. The amount of absorption of sulphur is said to be from 13 to 18 per cent by weight, based upon the portion of the concrete penetrated. The impregnation of portland cement concrete and mortar with molten sulphur increases their tensile and compression strength to a remarkable degree. Standard tensile briquets of cement mortar, which ordinarily break at about 150 pounds, are increased to over 1,000 pounds per square inch. In a representative mix of concrete using one part of cement to five parts of aggregate, the untreated mixture gave a compression strength of 1,665 pounds per square inch; whereas the sulphur treated concrete gave a compression strength of 8,600 pounds per square inch. The great increase in strength of concrete by impregnating with sulphur has been explained by the fact that sulphur contracts when solidifying and the crystalline forces tend to bind the entire mass together.

It is stated that commercial flour of sulphur, or sulphur in any other form, added to the concrete mix has little or no effect on the strength, even though this contained sulphur is subsequently melted. The best effect is obtained, apparently, by immersing the precast concrete product in a bath of molten sulphur, first under a vacuum, then under high pressure, and then under vacuum after the sulphur is drained off. The treatment of the concrete when seven days old is practically as good as the treatment of fully hardened concrete.

A process for treating with sulphur is covered by patents, U. S. No. 1,551,574 and U. S. No. 1,561,767.

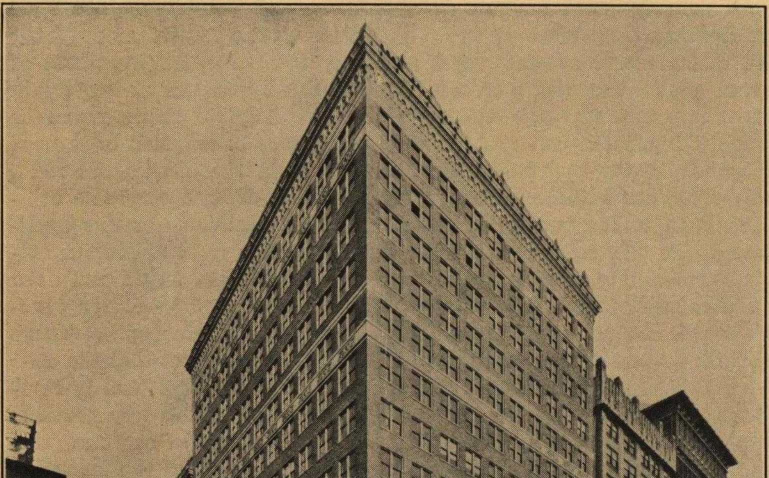

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FIG. 8—A representative structure in which additional floors were made possible by the use of special light weight concrete, workability improved, yields increased, and cost of form work reduced by the use of a plasticising agent.

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